# HAND ACTIVITY LEVEL

## TLV

Although work-related musculoskeletal disorders can occur in a number of body regions (including the shoulders, neck, low back, and lower extremities), the focus of this TLV is on the hand, wrist, and forearm.

The TLV shown in Figure 1 is based on epidemiological, psychophysical, and biomechanical studies and is intended for "mono-task" jobs performed for 4 or more hours per day. (A mono-task job involves performing a similar set of motions or exertions repeatedly, such as working on an assembly line or using a keyboard and mouse.). The TLV specifically considers average **hand activity level** or "HAL" and **peak hand force**. It is set for conditions to which it is believed that nearly all workers may be repeatedly exposed without adverse health effects.

HAL is based on the frequency of hand exertions and the duty cycle (distribution of work and recovery periods). HAL can be determined with ratings by a trained observer, using the scale shown in Figure 2, or calculated, using information on the frequency of exertions and the work/recovery ratio as described in Table 1.

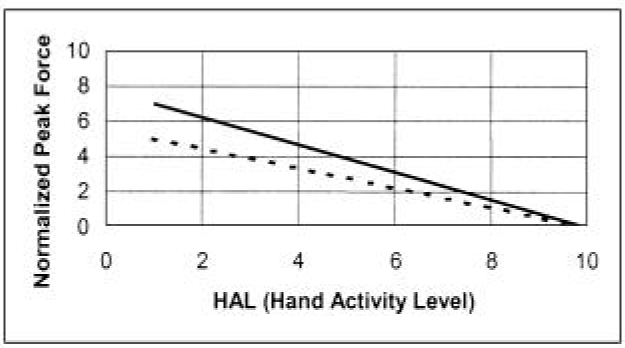


**FIGURE 1.** The TLV for reduction of work-related musculoskeletal disorders based on "hand activity" or "HAL" and normalized peak hand force. The top line depicts the TLV. The bottom line is an Action Limit for which general controls are recommended.

Peak hand force is normalized on a scale of 0 to 10, which corresponds to 0% to 100% of the applicable population reference strength. Peak force can be determined with ratings by a trained observer, rated by workers using a Borg scale [see TLV Documentation for definition], or measured using instrumentation, e.g., strain gauges or electromyography. In some cases, it can be calculated using biomechanical methods. Peak-force requirements can be normalized by dividing the force required to perform the job by the strength capability of the work population for that activity.

The solid line in Figure 1 represents those combinations of force and hand activity level associated with a significantly elevated prevalence of musculoskeletal disorders. Appropriate control measures should be utilized so that the force for a given level of hand activity is below the upper solid line in Figure 1. It is not possible to specify a TLV that protects all workers in all situations without profoundly affecting work rates. Therefore, an action limit is prescribed at which point general controls, including surveillance, are recommended.

### Example

1. Select a period of the job that represents an average activity. The selected period should include several complete work cycles. Videotapes may be used for documentation purposes and to facilitate rating of the job by others.
2. Rate the Hand Activity Level using the scale shown in Figure 2. Independent rating of jobs and discussion of results by three or more people can help produce a more precise rating than individual ratings.
3. Observe the job to identify forceful exertions and corresponding postures. Evaluate postures and forces using observer ratings, worker ratings, biomechanical analysis, or instrumentation. Normalized peak force is the required peak force divided by the representative maximum force for the posture multiplied by 10.

### Consideration of Other Factors

Professional judgment should be used to reduce exposures below the action limits recommended in the HAL TLVs if one or more of the following factors are present:

- Sustained non-neutral postures such as wrist flexion, extension, wrist deviation, or forearm rotation;
- Contact stresses;
- Low temperatures; or
- Vibration.

Employ appropriate control measures any time the TLVs are exceeded or an elevated incidence of work-related musculoskeletal disorders is detected.

**TABLE 1. Hand Activity Level (0 to 10) is Related to Exertion Frequency and Duty Cycle (% of work cycle where force is greater than 5% of maximum)(1,2)**

| | | Duty Cycle (%) | | | | |
|---|---|---|---|---|---|---|
| **Frequency (exertion/s)** | **Period (s/ exertion)** | **0–20** | **20–40** | **40–60** | **60–80** | **80–100** |
| 0.125 | 8.0 | 1 | 1 | — | — | — |
| 0.25 | 4.0 | 2 | 2 | 3 | — | — |
| 0.5 | 2.0 | 3 | 4 | 5 | 5 | 6 |
| 1.0 | 1.0 | 4 | 5 | 5 | 6 | 7 |
| 2.0 | 0.5 | — | 5 | 6 | 7 | 8 |

*Notes:*
1. Round HAL values to the nearest whole number
2. Use Figure 2 to obtain HAL values outside of those listed in the table.

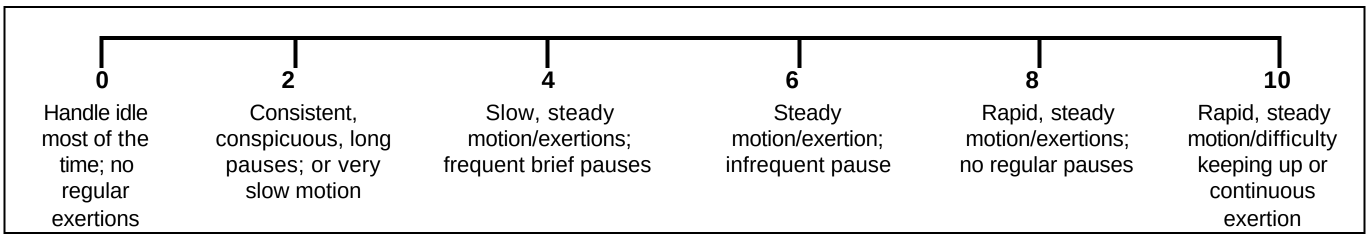


**FIGURE 2.** Hand Activity Level (0 to 10) can be rated using the above guidelines.

# DOCUMENTATION

## Background

### *Introduction*

Upper extremity musculoskeletal disorders (MSDs) include primarily soft tissue disorders of the muscles, tendons, ligaments, peripheral nerves, joints, cartilage, bones and or supporting blood vessels in the neck, shoulder, arm, elbow, forearm, hand or wrist. Examples of specific disorders include tension neck syndrome, cervical syndrome, rotator cuff tendinitis, epicondylitis, peritendinitis, and carpal tunnel syndrome (CTS). While these disorders may involve different mechanisms and manifestations there are many similarities that support a common approach for prevention. These similarities include the gradual onset of pain and other symptoms, the involvement of personal and work-related factors. Conditions that involve both work and personal factors are commonly referred to as “Work Related.”

“Work-related diseases" are those for which the etiologic factors include conditions within the work environment and those associated with the performance of work, even when the etiology is multifactorial, that is, that a number of risk factors (occupational or not) contribute to the causation of disease (WHO 1985). When MSDs are caused or aggravated by workplace risk factors such as repeated or sustained exertions of the body, and which are not the result of instantaneous events (slips or falls), they are called work-related musculoskeletal disorders (WMSDs). Considerable research has provided evidence that workplace factors, both working conditions and the performance of work, play a major role in the development of musculoskeletal disorders. Often these features of work interact in a multifactorial fashion to contribute to the development of MSDs. In 1997, the National Institute for Occupational Safety and Health (NIOSH) published a comprehensive literature review of the epidemiologic literature on musculoskeletal disorders (MSDs) and occupational exposures (Bernard, 1997). The Institute concluded that there was adequate evidence for causal relationships between MSDs of several body regions and repetitive motion, forceful exertions, non-neutral postures, vibration, and combinations of occupational exposures.

The relationship between WMSDs and

workplace risk factors cannot be represented by a straightforward one-to-one mapping. WMSDs can result from an interaction of physiologic, mechanical, individual, and organizational factors. As a result of exposure to a number of stressors in the workplace, repeated or continuous insult may take place in musculoskeletal tissues, affecting their integrity and their ability to function normally and result in WMSDs. These insults may either occur locally (e.g., from direct pressure or friction) or involve central neural mechanisms (e.g., inflammatory responses, pain modulation). The end result may be strengthening of some tissues and degenerations of others. In some cases the hypertrophy of one tissue may lead to mechanical insult and damage to another (Armstrong et al., 1993). Similar risk factors acting on different parts of the musculoskeletal system have similar effects. In general, those risk factors that overload the soft tissues, combined with inadequate recovery time for those tissues, are likely to lead to musculoskeletal disorders (Armstrong et al., 1993). Models that describe the relationship between work factors and tissue loads and the relationship between tissue loads and physiolgical responses provide a framework for designing and interpreting psychophysical and epidemiological studies to determine acceptable exposure limits.

## *Magnitude of the problem*

WMSDs and their risk factors have been identified in all industry sectors (Bernard, 1997; Silverstein et al., 1998; Foley and Silverstein, 1999). There are a variety of estimates of the magnitude of WMSDs in the US (Table 2). While workers compensation claims incidence data provide a higher estimate than BLS data, both tend to underestimate the true magnitude of the problem in the U.S. (Silverstein et al., 1998; Morse et al., 1998; Pransky et al., 1999). For example, 2% of the industrial workforce suffers a compensable back injury every year (Bond, 1970) but only 1 in every 10 results in a claim (Chaffin, 1979). Direct workers' compensation cost estimates are approximately $6 billion annually for gradual onset upper extremity disorders (Silverstein et al., 1998). These studies provide conclusive evidence that WMSDs are a major health and economic burden for workers and employers.

In a survey of Dutch employers, Houtman et al. (1998) reported the percent of 338 employers who believed the following risk factors to be problems for employees: force (22.2%), dynamic load (12.9%), posture (13.4%) and vibrations (3.1%). Forty-five percent of those employers reported musculoskeletal problems in their workplaces. These estimates were quite similar to a smaller Dutch survey of 782 employers (Houtman et al., 1998) (Table 3).

In survey of 5000 employers stratified on Standard Industrial Codes and size of work force, Foley and Silverstein (1999) found that about 8% of the work population was exposed to repetitive upper limb movement form more that four hours per day (Table 4). Other significant exposures include forceful exertions, pounding with the hands, fixed postures, and intensive keyboard work. Similar exposures can be expected in other industrialized parts of the nation and constitute a substantial public health concern. It is doubtful that any other exposure considered in the ACGIH TLV guide applies to this many people.

## *Epidemiologic evidence for TLVs to prevent WMSDs*

The conclusions of Bernard (1997) were stated in a qualitative manner, meaning that the authors did not seek to define the magnitude of the increase in risk associated with a specified increase in any of the causal factors identified. This review was not intended to repeat or replace the NIOSH study, but to identify the subset of the literature that helps to identify those exposure levels where the risk of WMSDs increases. While a number of work-related psychosocial risk factors have been identified in the epidemiologic literature (low decision latitude, high job demands, job dissatisfaction, low social support, working under deadlines), the focus is on physical factors at work. Similarly, this review acknowledges the various individual and life style factors that may also contribute to the development of musculoskeletal disorders but considers them as potential confounding variables rather than of primary interest, since the focus is to identify the occupationally preventable fraction of MSDs.

The selection criteria for the epidemiologic literature potentially relevant to a TLV were the following:

Methodologically stronger studies, according to the criteria specified in the NIOSH document, including both those identified as such by Bernard and any studies not included in that review which also met the same methodological criteria;

Studies that documented readily observable exposure features, which could be intervened on in the workplace; and

Quantitative documentation of exposure thresholds or exposure-response curves in at least one dimension of exposure studied.

Using these criteria relevant studies were identified. Exposure levels at which there was a significant increase in risk of upper extremity MSDs were extracted and categorized. Studies of repetition are summarized in Table 5. Where necessary, exposure values were converted so that frequency could be uniformly expressed in terms of times per hour and duration as hours per day.

Studies of force are summarized in Table 6 and studies of posture are summarized in Table 7.

Although factors are often isolated for study purposes, it must be recognized that many workers are exposed to multiple factors at once. Biomechanical studies suggest that there are likely to be interactions between these factors. This hypothesis is supported by epidemiological studies, which show that exposure to multiple physical risk factors for MSDs is additive or multiplicative (Silverstein et al., 1986, 1987; Chiang et al., 1993; Moore and Garg, 1994; Roquelaure, 1997; Punnett, 1998). For example, Silverstein and colleagues found that there was a multiplicative interaction between highly repetitive jobs and high manual force demands (see Tables 4 and 5 for risk factor definitions). Nilsson et al. (1994) reported an interaction between segmental vibration exposure and duration of forced gripping; Fransson-Hall (1995) found increased risk associated with combinations of repetitive motion and non-neutral wrist postures; Roquelaure et al. (1997) showed a continuous increase in risk with the number of occupational exposures; and Lynch et al. (1997) reported interactions between average cycle frequency and several measures of finger and wrist motions.

Blanc et al (1996) used 1988 National Health Interview Survey data to look at disability associated with CTS (cessation of employment either because of CTS or without attribution). Disability was found to increase significantly with the duration of exposure to repetitive bending/twisting of the wrist (OR for 120 minutes of exposure per day =1.7, 1.1-2.6; see Table 6). These data support 2 hours of repetitive wrist bending or twisting as a TLV. In a survey of the Dutch general population, Atroshi et al. (1999) reported a prevalence of 4.9% for electrodiagnostic & symptoms confirmed CTS. The prevalence for those reporting more than one hour per day of several risk factors was significant compared to those reporting less or no such exposure: excessive force with the hands during work was 5.4% versus 1.8% ($p<0.001$), excessive wrist flexion/extension 3.8% versus 1.7% ($p<0.01$), and 5.5% and 2.4% for the use of vibratory tools ($p<0.05$). These data support TLVs of 1 hour exposure per day to the factors specified. It can be seen from Table 5 that *there is significant risk of WMSDs exposures to high repetition for more than 4hours per day*. Of all of the studies listed in Table 5, Latko et al. (1999) is the only one to examine more than two levels of repetition. This study examined three levels from very low repetition to very high repetition and found that the morbidity of non-specific pain, tendinitis and carpal tunnel syndrome increased monotonically with increasing repetition. It is important to note that these data do not show a conspicuous threshold that is often observed for chemical exposures.

Studies in Tables 6 and 7 suggest that when exposures are combined with elevated force and posture that the risk of WMSDs may become significant with exposures as low as 1 hour per day. The average forces range from about 10 to 40N. This corresponds to 2% to 8%MVC for average male grip strength and 3.3% to 67% for average female pinch strength. Rohmert (1973) found that is not possible to sustain more than 15% of maximum force. Byström and Kilbom (1990) found that it was not possible to sustain more than 17% MVC for static work or 21% MVC for intermittent work. *These data support a TLV in which force decreases with increasing repetition.* Theoretically it should approach zero at the highest imaginable repetition levels as defined by Latko et al. (1997).

Marras and Schoenmarklin (1993) used an electrical goniometer to compared wrist postures and movements of a “high risk” WMSDs population (mean incidence of OSHA reportable cases was 11.4 cases per 200,000 work hours) with a “low risk” population (0 cases). The mean flexion/extension acceleration for the high-risk group was 824+268º/sec$^2$ versus 494+156º/sec$^2$ for the low risk group. It was proposed that wrist velocity and acceleration could be used as a surveillance tool to quantitatively assess the risk of MSDs. It also could be argued that it supports a TLV somewhere between the two extremes. Other studies using goniometers and electromyography to directly assess work intensity include: Hågg et al. (1997); Loslever and Ranaivosoa (1993); Malchaire et al. (1997); Ohlsson et al., (1994); Schoenmarklin et al. (1994). For the most part, these studies have observed high forces (> 15% MVC), motion velocities between wrist extension and flexion, and the duration during which the worker is above or beyond certain postural limits in jobs with high risk of upper extremity WMSDs. At present, it is difficult to translate this information into observational measures for this review.

It should also be noted that exposure to hand-arm vibration has been associated with a number of upper limb disorders in addition to HAVS (Bovenzi & Zadini, 1991). However, because ACGIH has a TLV for segmental vibration, it is not addressed directly in this review.

The epidemiologic literature on upper extremity MSDs in VDU operators was recently reviewed by Punnett & Bergqvist (1997). Upper extremity soft-tissue disorders among clerical users of video display units (VDUs) were found to be related overall to keyboard use, especially for four or more hours per day and in data entry and similarly intensive or repetitive VDU work (Table 5). It does not appear, however, that the incidence of conspicuous hand

and wrist pathology is as high in office workers as in industrial workers. This difference might reflect the difficulty in gaining access to and studying workers who perform very high repetition job. It might also reflect the difference in force requirements of keyboard work versus manufacturing work. The force ranges reported in Table 4 are from 10 to 40N, while average forces for keyboard work are approximately 1N (Gerard et al., 1999). There was also a large body of studies indicting poor workstation ergonomics and resultant postural stresses. Many of these available studies did not provide quantitative exposure values; others presented associations with continuous exposure variables that did not permit determination of threshold values. However, the findings were qualitatively consistent with those discussed above. The literature on computer mouse use is still very limited, although among CAD operators, UE MSD risk was associated with mouse location away from body and the hours of mouse use per day (Karlqvist et al., 1996). Thus, we have chosen not to propose a TLV value specific to VDU or mouse work, but rather to include these jobs among those covered by a generic TLV. In addition, a number of intervention studies provide further evidence of the multidimensional nature of the causal relationship in VDU work and have demonstrated the feasibility of prevention through ergonomically adjusted workstations and chairs; training (including how to make appropriate workstation adjustments); improved work organization; and improved general physical environment.

Psychosocial features in the work environment are another category of preventable exposures that have been associated in some studies with upper extremity MSDs (e.g., Houtman et al., 1994; Leino & Hänninen, 1995; Hughes et al., 1997). However, these have not generally been assessed in a way that would permit the determination of appropriate TLVs. In future research, interview items on psychosocial risk factors need to be identified with "upstream" factors that can be observed and intervened on, such as piece-rate wages (Brisson et al., 1989), and technology design or work organization factors that interfere with work performance (Greiner et al., 1997).

Other reviews of the literature by Kilbom (1994b) and Winkel and Westgaard (1992a or b?), led to similar findings and guidelines (Tables 8 AND 9). Both of these reviews recognized that the combination of risk factors increases the risk for upper extremity MSDs.

### *Other Guidelines and Standards for Exposure to Work Factors*

Table 10 summarizes current standards and guidelines of different countries, states or provinces. For the most part, quantification is lacking in these regulations. The Japanese Ministry of Labor has had keyboard guidelines since the 1970s, updating them to include VDUs in the 1980s. These guidelines require hourly breaks and limit the number of keystrokes and total keying time. The Department of Labor and Industry of the state of Maine requires VDT operators (defined as anyone having primary task of operating a terminal for more than four consecutive hours exclusive of breaks) to be provided with training on the use of VDUs and protective measures, with annual refresher training. New Zealand recommends 10-minute breaks every hour and microbreaks every 3 minutes for intensive VDU work (1995).

Australia has had a manual handling regulation since 1990 and codes of practice for manual handling and occupational overuse syndrome since 1993 (Worksafe Australia, 1993 1994 and 1990 in bib), as does New Zealand. These regulations address repetitive upper extremity work, in addition to manual materials handling activities more typically thought of in relation to low back disorders. In these codes, if handling is performed for more than one hour at a time, risk assessment is then required. This includes actions if there is repeated action of 10-18 per minute or for more than an hour in a workday, maintaining a force, holding a grip or position, for more than 10 seconds or overhead work more than 30 seconds. The regulations give many examples of exposure limits to consider while doing a risk assessment. These are largely in agreement with the guidelines of Kilbom, Westgaard and Winkel, and the NIOSH lifting equation (Waters et al., 1993). The Victoria regulation and codes of practice are undergoing revision and are considering including quantitative risk assessment methods including the 1991 NIOSH Lifting Equation, Rapid Upper Limb Assessment Method (RULA), Rapid Entire Body Assessment (REBA), UM 3D Static Strength Prediction Model, OWAS, and Job Severity Index (Victorian Work Cover Authority, 1998).

## Recommended Exposure Limit

ACGIH recommends the threshold limit value for exposure to 4 or more hours of repetitive hand work per day shown in Figure 1. The TLV is intended for monotask type jobs, but might be extended to multi task jobs by using time weighted exposures

Professional judgment should be used to recommend TLV reductions when exposures include work related risk factors of musculoskeletal disorders, such as:

- Sustained non-neutral postures such as flexion, extension, or forearm rotation;
- Contact stresses
- Low temperatures; or

- Vibration

### *Action Limit*

Because use of the hands is fundamental to work, it is not feasible to establish a TLV that will protect all workers. Persons applying the TLV should be aware of the strength differences among occupational groups, genders and ages. We believe that there will still be some persons who experience symptoms at the TLV. Therefore, an action limit is also specified that requires administrative controls including education and surveillance so that musculoskeletal disorders can be identified and appropriate interventions implemented while disorders are in their earliest stages.

### *Hand Activity Level (HAL)*

Repetition is characterized using the 0 to 10 Hand Activity Level scale (0=completely idle and 10 = the greatest level of repetition imaginable) proposed by Latko et al. (1997ab) (see Figure 2). A linear regression model was produced from the data published by Latko et al. (1997b) for 33 jobs. The dependent variable was Hand Activity Level (HAL), and the independent variables were exertion period (s/exertion) and duty cycle. The linear fit had a coefficient of determination ($r^2$) of 0.71. A table of HAL values (0-10) corresponding to different combinations of exertion frequency, exertion period, and duty cycle based on the regression model is shown in Table 1.

### *Normalized Peak Force*

Normalized peak force is a fraction of the individual or population strength and should be adjusted according to the population of interest.

$$\text{Normalized Peak Force} = \frac{\text{Peak force}}{\text{Strength}}$$

where:

Peak force = the peak force for the job or task under study and is expressed in kilograms, pounds or newtons

Strength = the individual or population under study using same posture as observed for the peak force element.

Peak normalized force is the peak force divided by the strength of the work population to which the standard is applied. Although the term “peak” is used, as a practical matter it is a 90$^{th}$ percentile value. The 90th percentile was used so that the peak force would not be driven by random or spurious work elements.

#### TLV Basis

With respect to hand motion or activity level, Table 5 summarizes relevant epidemiological data that are consistent with the TLV. Roquelaure (1997) and Leclerc et al. (1998) reported increased risk with cycle times less than 10 seconds; Silverstein et al. (1987) characterized high repetitiveness as more than 50% of the cycle time repeating the same fundamental cycles.

With respect to normalized peak force, Table 6 presents the epidemiological data that provided a quantitative estimates of force. The mean force values for elevated risk in the studies by Silverstein et al. (1987), Stetson et al. (1993), and Chiang et al. (1993) can be roughly compared to the population values for maximum grip and pinch strength values reported by Mathiowetz et al. (1985), and represent approximately 10-14% MVC. Roquelaure (1997) identified increased risk of CTS when pinching objects exceeding 10N in weight. Franson-Hall (1995, 1996) and Byström and Fransson-Hall (1994) also identified repetitive forceful pinching as increasing risk. Silverstein and Roquelaure also reported increased risk of CTS with increasing number of risk factors. These studies are consistent with the TLV.

The normalized peak force (Table 1) decreases from a maximum value of 7 for a hand activity level of 1 to 0 for a hand activity level of 10. Hand activity levels less than 1 were omitted because they are not considered repetitive work and outside the scope of this standard. A hand activity level of 1 corresponds to a duty cycle of 20% (see Table 1). Therefore the average normalized force should not be greater than 0.14 (0.2*7), or 14%MVC, which is consistant with the values reported in Table 6. 15% of maximum strength is considered an upper limit for fatigue in most studies of localized fatigue (Rohmert 1973; Byström and Fransson-Hall 1994).

Studies shown in Table 6 characterized force exposure as an average value, while the TLV is based on “peak normalized force.” The average force has been shown to be related to the peak force. Silverstein et al. (1987) reported that the 97.5%tile force was 2-4 times greater than the average value. Gerard et al. (1996) reported that the 90$^{th}$ percentile force for keyboard work was about two times the average value. Thus the proposed TLV is placed liberally at or above levels at which health findings were reported in the epidemiologically studies reported in Table 6.

Subsequent studies of manufacturing jobs show that the prevalence of non-specific pain, tendon disorders and nerve disorders increases linearly from low repetition to medium to high repetition. The TLV was set at zero for a HAL value of 10 --- “Rapid Steady Motion/Continuous Exertion.” While some have argued that exertions as high as 15% of maximum strength can be sustained at continouosly, others have argued that continous exertions at any level are fatiguing. Since a repetition rating of 10 implies that there is "Rapid Steady Motion" it is likely that the inertial forces would be well above 15% of maximum strength (Marras 1993; Rohmert 1973; Byström and Fransson-Hall 1994).

Studies listed in Table 7 show increased risk with wrist deviations but it is unlikely that these occurred in the absence of forceful or repetitive exertions and thus would increase the complexity of the TLV. It should be noted that extreme postures increase force requirements and professional judgment should be used to lower the values in the TLV when extreme postures are present.

## *Comparison of TLV with Psychophysical Studies*

The proposed TLV was compared to published hand-wrist psychophysical studies by computing the force level predicted by the Lin and Radwin (1998) model for the equivalent discomfort in which the discomfort level was 3.4. (Note: the Lin and Radwin (1998) findings agreed favorably with those of Kim and Fernandez, 1993; Marley and Fernandez, 1995; Snook et al., 1995) Frequencies for various levels of HAL, based on a 50% duty cycle, were determined using Table 1. Corresponding frequencies for HAL levels of 2, 5 and 8 are shown in Table 11. Based on the equivalent discomfort model, the force needed to produce a discomfort level of 3.4 was predicted for each repetition frequency. Consider if a 50th percentile female wrist flexion torque MVC of 8 Nm (Eastman Kodak, 1986) was equivalent to a hand force of 69 N for a female of 182 cm stature. The %MVC hand force for the predicted force levels are given in Table 11. Based on this analysis, the Action Limit exceeds the exposure level considered acceptable for a repetitive flexion task without developing unusual discomfort at the end of a seven hour session, as found by Snook et al. (1995).

### *Comparison of TLV to Other Guidelines*

Comparison to other guidelines is hampered by a lack of guidance for highly repetitive tasks; most research has concentrated upon longer static holds and these rarely present holding times below 30 seconds. Table 12 shows the values from the Strain Index proposed by Moore and Garg (1995). The effort values corresponding to a Strain Index of 5, as proposed by the authors, in general, lie under the administrative control TLV.

### *Assessing Force*

"Normalized peak hand force" is expressed on a scale of 0 to 10 where 0 corresponds to no effort and 10 corresponds to 100% maximum effort. Normalized peak hand force is determined for a given task by:

1. Measuring hand forces and corresponding postures,
2. Obtaining strength data for that posture and that worker or work population. In most cases strength values can be obtained directly or extrapolated from the literature, and
3. Calculating "Normalized Peak Hand Force" by dividing required force by strength.

Methods for assessing hand force include:

- Worker ratings
- Observer ratings
- Biomechanical analyses
- Force gauges
- Electromyography

#### WORKER RATINGS

Visual analogue scales and the Borg (1982) scales are commonly used to obtain worker ratings on a scale of 0 to 10. A visual analogue scale is shown in Figure 3. It typically consists of a 10-cm horizontal line. The left end of the scale is labeled "no effort;" the right end of the scale is labeled as "greatest effort imaginable." The worker is simply asked to draw a horizontal line through the scale at a location that most closely corresponds with the peak effort associated with their job. The job is scored by measuring the distance of the mark from the left end of the scale. The Borg scale, shown in Figure 4, entails a series of verbal anchor points. The worker is asked to identify the descriptor that most closely approximates the peak effort associated with his or her job.

Both the Borg and visual analog scales assess the effort of the individual performing the rating. While this may be important information about that person, it is necessary to know the strength of that individual with respect to the rest of the population to calculate the normalized force. For example, suppose that a female worker rates the job grip strength requirements as a four. The worker's maximum grip strength is then measured and found to be 300N; but the fifth percentile female grip strength is approximately 183N and the fifth percentile male strength is approximately 383N. [It is common practice to design for lower percentiles; however, the normalized force can be adjusted for other individuals, 9occupational groups, and other percentiles by selecting appropriate strength values from Table 14. the fifth percentile male is an estimate, based on an average coefficient of variation of 19.2% from data reported in Table 14 and the average female strength of industrial applicants as reported in Schmidt and Toews (1970)] The peak force rating on the ten-point scale can then be estimated as:

$$\text{5\%ile female normalized hand force} = \frac{(4 \bullet 300\text{n})}{183\text{N}} = 6.6$$

$$\text{5\%ile male normalized hand force} = \frac{(4 \bullet 300\text{N})}{383\text{N}} = 3.1$$

The precision of worker ratings can be improved by averaging the normalized ratings of multiple workers doing the same job.

OBSERVER RATINGS

Observers can use visual analog scales to rate force exposures. Zero, the left end of the scale, corresponds to "no perceptible force." In this case the workers' hands would be resting on his or her lap, a work surface, keyboard, etc. Ten, the right hand end of the scale, corresponds to the "greatest force imaginable." In this case the worker would demonstrate visible strain, tensed muscles, jerking, etc. It is helpful to videotape examples of jobs that represent the extremes and points in between that can be used as reference points. These may be used to develop suitable verbal reference points for the occupation or industry of concern. As a practical matter it may be only possible to group jobs into 3 to 5 intervals between zero and ten. Having multiple observers rate the job and discuss their results can increase the precision of observer ratings. Factors that should be considered include:

- Strength of the observed worker versus the population of interest.
- Weight, shape and friction of work object
- Posture
- Glove fit and friction
- Mechanical assist
- Torque specifications of power tools
- Quality control
- Equipment maintenance

Professional judgment based on a basic understanding of hand biomechanics is required for reliable force estimates.

BIOMECHANICAL CALCULATIONS

Biomechanics entails the use of mechanics to estimate the load on the fingers. A biomechanical analysis should begin with a free-body diagram of the object being grasped. The vector sum of the forces and moments must add up to zero. In most cases the analysis can be simplified by using a two-dimensional approximation of the work object. Figure 5 shows two examples.

In Case A the worker is holding an object with a hook grip. In this case the load on the fingers will be equal to the force of gravity on the object: $F_{grip}=W_{object}$. If the object weighs 25N, then $F_{grip}$=25N. The hook grip strength is very close to power grip strength. As listed in Table 14, the average male and female power grip strength for industrial applicants is 503N and 311N, respectively. Therefore, on the 10-point scale, the normalized force to hold the book ranges from 0.5 to 0.8 for the average female to average male. As a practical matter the values might be increased 1 point each to account for acceleration.

In Case B the worker is holding a book in a vertical pinch grip. In this case the fingers must apply enough contact force to the sides of the book to produce enough friction force to overcome the force of gravity. The required pinch force is related to the weight and friction by the following inequality:

$$F_{pinch} \geq \frac{W_{book}}{2\mu}$$

The coefficient of friction depends on the surface material and moisture of the skin (see Table 13). Often it will be found that the skin loses moisture to the work objects and dries out. For moist skin and paper, the coefficient of friction is approximately 0.5; for dry skin it is approximately 0.25. The pinch force can be calculated as:

$$\text{Moist skin}: F_{pinch} \geq \frac{25}{(2 \bullet 0.50)} = 25\,\text{N}$$

$$\text{Dry skin}: F_{pinch} \geq \frac{25}{(2 \bullet 0.25)} = 50\,\text{N}$$

The calculated values are then compared with the corresponding hand strength. In this case, the hand is in a pinch posture. From Swanson et al. (1970), pinch strength is approximately 15% of power grip strength. Therefore, the normalized peak forces on the 10-point scale will be:

*For the Female*

$$\text{Moist skin}: \left[\frac{25\text{N}}{(0.15 \bullet 311\text{N})}\right] \bullet 10 = 5.4$$

$$\text{Dry skin}: \left[\frac{50\text{N}}{(0.15 \bullet 311\text{N})}\right] \bullet 10 > 10$$

*For the Male*

$$\text{Moist skin}: \left[\frac{25\text{N}}{(0.15 \bullet 503\text{N}}\right] \bullet 10 = 3.3$$

$$\text{Dry skin}: \left[\frac{50\text{N}}{(0.15 \bullet 503\text{N})}\right] \bullet 10 = 6.7$$

Females with average strength and dry skin would not be able to hold the book in a pinch posture. These are only the minimum force requirements for a static exertion. Often it is found that workers exert more than the necessary force (Frederick and Armstrong, 1995; Westling and Johansson, 1988). Also the force requirements must be increased to compensate for acceleration. As a practical matter, these values should be rounded to the nearest whole number.

FORCE GAUGES

In some cases, force gauges can be incorporated into the work object. Force gauges are often placed under keyboards to estimate finger forces in keying. As a practical matter, these methods require custom instrumentation. Also, there are many instances, such as the above examples, where there are significant technical barriers to incorporating force sensors into the work object. The technical details of these methods go beyond the scope of this discussion.

ELECTROMYOGRAPHY

Electromyography involves using the electrical activity of the muscles to estimate the force exertion of the hand. While this method is widely used in laboratory and field settings, it requires specialized equipment and training. Key issues include:

- Selection of the appropriate muscle group
- Proper placement of surface electrodes
- Calibration
- Data acquisition and processing
- Data analysis and interpretation

Armstrong et al. (1982) have demonstrated how this equipment can be used to estimate hand forces as a function of time in poultry processing. Other investigators have subsequently proposed methods for summarizing EMG data using probability distributions (Jonsson 1988; Mathiassen and Winkel, 1991). EMG data can be calibrated as a fraction of an individual's maximum, which for practical purposes corresponds to the normalized hand force. Bao et al. (1995) describes several techniques for EMG calibration. The user should be aware that there is significant variation in EMG data and, therefore, signal-processing routines that filter the data are required.

Like worker ratings, these data provide information about an individual person and it may be necessary to adjust the findings based on the ratio of the strength of the individuals to that of the population.

## *Examples*

EXAMPLE 1: CASE PACKING – MACHINE PACED:

In this example a worker uses both hands to get a flattened shipping carton from a stack next to the work station, erects it and places it between him and the end of the conveyor. He then alternates right and left hands to get boxes of product weighing 8N each from the end of the conveyor and places them in the shipping carton. He then use both hands to close the flaps on the carton and push it aside into an automatic taping machine.

- Get and erect shipping carton: 5s Right and left hands used together (100% work [duty cycles based on observation])
- Pack six 8N boxes: 15s Alternate use of right and left hands (40% work)
- Close case and aside into taping machine: 2s Right and left hands used together (100% work)

*Cycle Time* = Time to construct carton + time to pack carton + time to close & aside carton
= 5 s (3 exertions) + 15s (3 exertions) + 2s (2 exertions) = 22 s
= 22s/8 exertons
= 2.75s/exertions

*Duty Cycle* = (100%work • 5s + 40%work • 15s + 100%work • 2s) / 22s
= 60%

*Hand Activity Level*: Because the job involves conspicuous rest pauses and the worker does not have to hurry, HAL has been rated using Figure 2, based on observation, as 4. Alternatively, using Table 1 along with the time per exertion and the duty cycle calculated above, the HAL is estimated to be 4.

Force is exerted to get and erect the cartons, to pack and to aside the case. The greatest forces are associated with picking up the boxes using a pinch grip. It is found that approximately 8N of force is required to pick up the carton.

The fifth percentile pinch strength for a female work population is estimated as 27N (0.15•183N), based on ratio of brip to pinch strength as reported by Swanson et al. (1970) in Table 14.

Normalized hand force = (8N/27N)•10, or approximately 3. From Figure 1 it can be seen that the worker is below the action limit.

EXAMPLE 2: CASE PACKING: SELF PACED

This case is the same as the above, except that the worker is paid on an incentive according to how much he or she packs. Although the worker is able to keep up, the 9s of recovery time for each hand that occurred during the packing step has been eliminated so that the duty cycle is 100%.

*Cycle Time* = 5 s (3 exertions) + 6s (3 exertions) + 2s (2 exertions) = 13s
= 13s/8 exertons
= 1.6s/exertions

*Duty Cycle* = (100%work • 5s + 100%work • 6s + 100%work • 2s) / 13s
= 100%

Using the scale in Figure 2, repetition has been rated as 6 – "steady motion/exertion; infrequent pauses." Alternatively, using Table 1 along with the time per exertion and the duty cycle calculated above, the HAL also is estimated to be 6.

While the force to hold the box is the same, it is reasonable to increase the required hand force one or two points to account for the inertial effect. The normalized peak hand force then becomes 4. From Figure 1 it can be seen that the worker is now above the action limit.

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## Tables

**TABLE 2. Estimates of WMSDs in the United States**

| **Type of WMSD** | **Year** | **Rate per 10,000 FTEs** | **Source** |
|---|---|---|---|
| Overexertion in lifting resulting in days away from work | 1998 | 53.8 | US BLS 2000 |
| Repetitive motion resulting in days away from work | 1998 | 7.4 | US BLS 2000 |
| Carpal tunnel syndrome resulting in days away from work | 1998 | 3. 0 | US BLS 2000 |
| Shoulder, elbow, hand, wrist gradual onset WMSD claims (WC) | 1987-95 | 96.4 | Silverstein, 1998 |
| Carpal tunnel syndrome (WC) | 1987-95 | 27.3 | Silverstein, 1998 |
| Rotator cuff syndrome (WC) | 1987-95 | 19.9 | Silverstein, 1998 |
| Epicondylitis (WC) | 1987-95 | 11.8 | Silverstein, 1998 |
| “Doctor-called” carpal tunnel syndrome (prevalence) | 1988 | 50.0 | Tanaka et al., 1995 |
| “Doctor-called” upper extremity WMSD (prevalence) | 1996 | 370.0 | Morse et al., 1998 |
| CTS resulting in cessation of work (prevalence) | 1988 | | Blanc et al., 1996 |

**TABLE 3. Percent of employers who reported WMSD problems and problematic exposure to ergonomic risk factors (Houtman, 1998)**

| | **General Industry (n=388)** | **Wholesale Trade (n=146)** | **Banking & Finance (n=198)** |
|---|---:|---:|---:|
| WMSD problems | 44.8% | 41.1% | 31.3% |
| **Physical Load factors** | | | |
| Force | 22.2% | 19.2% | 8.1% |
| Dynamic load | 12.9% | 7.5% | 4.0% |
| Awkward postures | 13.4% | 8.2% | 7.6% |
| Vibrations | 3.1% | 2.7% | 0% |
| Workpace | 16.5% | 13.7% | 23.2% |

**TABLE 4. Estimated prevalence of exposure to ergonomic risk factors (percent of employees), Washington State Employer Survey, 1998 (Foley and Silverstein, 1999)**

| **Risk Factor** | **Any exposure** | **0-2 hours** | **2-4 hours** | **>4 hours** |
|---|---:|---:|---:|---:|
| Lift ≥44.5N more than 1 time/minute | 20.6% | 1.9% | 1.6% | 2.9% |
| Use hand or knee as a hammer | 5.6% | 0.3% | 0.1% | 0.1% |
| Use vibrating tools -grinders, impact wrenches, etc. | 18.9% | 2.8% | 1.6% | 2.1% |
| Repeated pinch small objects or tools between thumb and fingers or hold them a long time | 23.3% | 2.3% | 3.9% | 2.7% |
| Work with non-powered hand tools | 28.9% | 4.1% | 3.7% | 4.0% |
| Work with hands above shoulder level | 21.4% | 5.4% | 1.7% | 2.2% |
| Repetitive movement of whole arm more than 2 times/minute | 29.5% | 3.7% | 2.8% | 6.1% |
| Hold fixed position while working (e.g., microscope work) | 19.2% | 1.6% | 1.1% | 2.3% |
| Move lower arm(s) more than 10 times/minute (exclude typing) | 28.1% | 4.3% | 4.2% | 6.3% |
| Use keyboard/mouse intensively (data entry) | 34.2% | 4.6% | 4.6% | 8.1% |

**TABLE 5. Level of exposure to repetitive manual work at which increased risk of upper extremity musculoskeletal disorders was found**

| **Repetitiveness** | **Duration** | **Reference(s)** |
|---|---|---|
| Work cycle <30 seconds | Full shift* | Silverstein et al., 1985(?), 1986, 1987; Armstrong et al., 1987; Chiang et al., 1993; Ohlsson et al., 1994 |
| More than 50% of work time in fundamental cycle | Full shift | Silverstein 1986, 1987; Armstrong 1987; Chiang 1993 |
| Work cycle 35 seconds (median value) | Full shift | Punnett et al., 1985,1987 |
| Work cycle <10 seconds | 4-8 hrs/day | Leclerc et al., 1998 |
| Shortest elementary operation <10 seconds | Full shift (7.5 hrs/day) | Roquelaure, 1997 |
| Median angular velocity (wrist) 41°/second and pauses = 0.6% of work time | Full shift | Ohlsson et al., 1994 |
| Repetitive hand and/or finger movements ("many times per minute") and/or manual precision requirements | >4 hrs/day | Fransson-Hall et al., 1995 |
| Keying-intensive visual display unit work (e.g., data entry) | >2 hrs/day<br>>3 hrs/day<br>>5 hrs/day<br>>6 hrs/day | Burt et al., 1990; Faucett & Rempel, 1994<br>Oxenburgh et al. 1987 (85?)<br>Polanyi et al., 1997<br>Bernard et al., 1993 |
| Medium repetitiveness (average rating 5.4 on 0-10 scale) – corresponds to approx. 0.75 exertions/sec. and 30% recovery per cycle | Full shift | Latko et al., 1999 |
| External constraints on work pace | | |
| Piece-rate wage system | Full shift | Brisson et al., 1989 |
| Lack of change in task or breaks during >15% of work time | Full shift (7.5 hrs/day) | Roquelaure 1997 |
| Just-in-time production system | 4-8 hrs/day | Leclerc et al. 1998 |

* "Full shift" implied or assumed to mean a work day of 7.5 to 8 hours in length

**TABLE 6. Level of exposure to manual exertion at which increased risk of upper extremity musculoskeletal disorders was found**

| **Manual forces** | **Duration and/or frequency** | **Reference(s)** |
|---|---|---|
| > 40N average hand forces * | Full shift | Silverstein et al., 1986, 1987; Armstrong et al., 1987 |
| > 30N average hand forces | Full shift | Chiang et al., 1993 |
| > 27N kg object weight per hand | Routine gripping >1/3 work shift | Stetson et al., 1993 |
| > 40N object weight, carried | Full shift: "usually" | Stetson et al., 1993 |
| > 10N object weight handled | >4 hrs/day | Fransson-Hall et al., 1995 |
| > 10N object weight, handled by pinching and fine prehensile finger motions | Full shift (7.5 hrs/day): >10 times/hr | Roquelaure 1997 |
| Forceful wrist/hand motions | | |
| Grocery checking | > 5 hrs/day | Baron 1991 |
| Repeated grasping and wrist flexion/ extension | > 4 hrs/day | Osorio et al. 1994 |
| Forearm rotation while exerting very high forces | 18 min/day (avg) | Hughes et al., 1997 |
| "Excessive" manual force | > 1 hr/day | Atroshi et al., 1999 |

* N.B. "adjusted force" was 6 kg by EMG; approx. equal to 4 kg cut-off in initial job selection.

**TABLE 7. Level of exposure to non-neutral upper extremity posture at which increased risk of upper extremity musculoskeletal disorders was found**

| **Posture** | **Duration and/or frequency** | **Reference(s)** |
|---|---|---|
| Wrist flexion or ulnar deviation* | > 4 hrs/day | Fransson-Hall et al., 1995 |
| Wrist bending or twisting* | > 3.5 hrs/day | Nordstrom et al. 1997 |
| Wrist flexion or extension* | > 3 hrs/day | De Krom et al., 1990 |
| Wrist bending or twisting * | > 2 hrs/day | Blanc et al., 1996 |
| Wrist flexion, extension or ulnar deviation >45°, or radial deviation >30°, or pinch grip | Full shift: repeated and/or sustained | Barnhart et al., 1991 |
| Wrist flexion or extension * | 600 repetitions/ hour | English et al., 1995 |
| Ulnar abduction >20° | Full shift: “typical” work posture | Hünting et al., 1981 |
| Shoulder angle > 30 degrees | Full shift: average duration 48% of shift, 600 times/hour | Frost & Andersen, 1999 |
| Shoulder flexion >60 degrees | Full shift: “typical” work posture | Bjelle 1981 |
| Shoulder flexion >60 degrees | Full shift: >45 arm movements / hour | Ohlsson et al., 1995 |
| Shoulder flexion >60 degrees | >15% of shift | Ohlsson et al., 1995 |
| Shoulder rotation with elbow flexed * | >60 times/hour | English 1995 |
| Shoulder rotation with arm elevated* | Continuous, >1 hr/day | English 1995 |
| Hands above shoulder level | >1 hr/day | Holmström et al., 1992 |
| Shoulder flexion or abduction >90 degrees | Full shift: >60 / hour | Punnett et al. (under review) |
| Shoulder flexion or abduction >90 degrees | > 10% of shift | Punnett et al. (under review) |
| No forearm support | > 4 hrs/day | Bergqvist et al., 1995a, 1995b |
| Neck flexion >56° in VDU work | Full shift: “typical” work posture | Hünting et al., 1981 |
| mean flexion/extension acceleration < $824+268°/sec^2$ but > $494+156°/sec^2$ | Full time manufacturing work | Marras & Schoenmarklin (1993) |

* threshold postural angle not specified.

**TABLE 8. Recommendations for dynamic or intermittent static movement in repetitive work (adapted from Kilbom, 1994a)**

| **<u>Body Area</u>** | **<u>Frequency</u> repetition per minute** | **Level of risk** | **Very high risk if modified by either:** |
|---|---|---|---|
| Shoulder | more than 2.5 | high | ♦ high external force, speed, high static load, extreme posture<br>♦ lack of training, high output demands, lack of control<br>♦ long duration of repetitive work |
| Upper arm / elbow | more than 10 | high | |
| Forearm/wrist | more than 10 | high | |
| Finger | more than 200?[??] | high | |

**TABLE 9. Limits on duration and condition of exposure to prevent neck and shoulder disorders (adapted from Winkel and Westgaard, 1992)**

| | **Condition** | **Duration** | **Reduce further if** |
|---|---|---|---|
| Low | Good work stations but static trapezius load | Less than 4 hours | ♦ high monotonous tasks<br>♦ low control-high demands<br>♦ high production intensity<br>♦ lack of breaks<br>♦ no task variety |
| Medium | Abducted/flexed shoulders, flexed/extended neck | 1 hour or less | |
| High | Large forces exerted | Less than 1 hour | |

**TABLE 10. Selected international guidelines and regulations intended to reduce upper limb MSDs.**

| | **Repetition/Motion** | **Force** | **Posture** |
|---|---|---|---|
| Sweden: Ergonomics for the Prevention of Musculoskeletal Disorders, 1998 | Red zone: If the work cycle is repeated several times per minute for at least half the shift | Aggravating factors: work requires a great deal of physical exertion, precision or speed of movement, if the work piece is heavy and difficult to grasp. | Red zone: constrained or uncomfortable work postures and movements |
| British Columbia: Musculoskeletal Injuries Regulation, 1998 | Must be considered (in terms of duration, frequency and magnitude) but not defined | Must be considered (in terms of duration, frequency and magnitude) but not defined | Must be considered (in terms of duration, frequency and magnitude) but not defined |
| UK: Display screen equipment work, 1992 | Daily user with prolonged spells of > 1 hour, with fast information transfer: requires breaks, preferably 5-10 minute breaks after 50-60 minutes continuous keyboard work | none | Consider layout and keyboard placement |
| Australia: National Code of Practice for Manual Handling (Occupational Overuse Syndrome), 1993. | Handling performed > 1 hour at a time,<br>• 10-18 times/minute,<br>• similar actions continuously >1 hour | Maintaining force or grip > 10 seconds,<br>> 4.5 kg handled from seated position | Is awkward grip used? |
| New Zealand: Guidelines for Prevention & Management of Occupational Overuse Syndrome, 1994 | Less than 30 second cycle time | Weight of tool >4.5kg<br>Pinch grip<br>Shock loading to hands | Wrist deviation, flexion, extension (no time frame) |
| Maine: Health & Safety Regulations: Video Display Terminal Operators, 1992 | VDT operator (primary task of operating a terminal > 4 consecutive hours exclusive of breaks) to receive training on the use of VDUs and protective measures | none | none |

**TABLE 11: Levels of %MVC and discomfort (10 point scale) that correspond with various levels of HAL for a 50% duty cycle (Lin & Radwin, 1998)**

| | **HAL** | | |
|---|---|---|---|
| | 2 | 5 | 8 |
| Frequency (Hz) | 0.1 | 0.75 | >2 |
| Predicted Hand Force (N) | 20 | 7 | <5 |
| %MVC Hand Force (%) | 29 | 10 | <7 |

| **TABLE 12: Levels of effort (on a 10 point scale) equivalent to a Strain Index of 5** | | | | | | |
|---|---|---|---|---|---|---|
| HAL[A] | 1 | 2 | 3 | 4 | 5 | 6 |
| Predicted Effort using Strain Index[B] | 3-7 | 3 | 2-3 | 3 | 2 | 2 |

[A]HAL obtained using Table 10 for a number of combinations of duty cycle (25, 50 and 75%) and cycle times (3, 6, 12 and 15 s)
[B]Levels of effort estimated at a Strain Index of 5. Values for the multiplier for hand/wrist posture, speed of work and duration per day have been set at unity.

**TABLE 13: Coefficients of Friction for Human Palmer Skin against Various Materials n=7 subjects (Buchholz et al., 1987)**

| **Material** | **Dry (n=42)** | **Moist (n=42)** | **Combined (n=84)** |
|---|---|---|---|
| Sand Paper (#320) | -- | -- | 0.61 ± 0.10 |
| Smooth Vinyl | -- | -- | 0.53 ± 0.18 |
| Textured Vinyl | -- | -- | 0.50 ± 0.11 |
| Adhesive Tape | 0.41 ± 0.10 | 0.66 ± 0.14 | -- |
| Suede | 0.39 ± 0.06 | 0.66 ± 0.11 | -- |
| Aluminum | -- | -- | 0.38 ± 0.13 |
| Paper | 0.27 + 0.09 | 0.42 + 0.07 | -- |

**TABLE 14: Power grip strengths in newtons from several studies: mean(standard deviation). Subject age is expressed as a range with mean and/or standard deviation listed where available. Statistics not reported in the study are listed as "nr".**

| | ***Dominant/ Right*** | ***Non-Dom/ Left*** | ***n*** | ***Subject Age*** | ***Population*** | ***Reference*** |
|---|---|---|---|---|---|---|
| ***Male*** | 463.5(nr) | 398.9(nr) | (nr) | 18-65 | Office workers | Nemethi, 1952 |
| | 532.1(nr) | 474.3(nr) | (nr) | 18-65 | Laborers | |
| | 556.6(nr) | 514.5(nr) | (nr) | 18-65 | Skilled | |
| | 589.0(nr) | 532.1(nr) | (nr) | 18-65 | Semi-skilled | |
| | 502.7(72.5) | 488.0(73.5) | 1128 | 18-62 | Steel mill applicants | Schmidt & Toews, 1970 |
| | 466.5(nr) | 441.0(nr) | 50 | 17-60 | U.S. Adults | Swanson et al, 1970 |
| | 428.3(63.7) | 409.6(71.5) | 34 | 18-67 | U.S. Adults | Young et al, 1986 |
| | 343.0(68.6) | nr | 35 | 16-28<br>22.5(2.1) | College students | Balogun et al, 1991 |
| | 609.6(106.8) | 574.3(98.0) | 105 | 16-63<br>32(nr) | U.S. Adults | Crosby et al, 1993 |
| | 479.2(82.3) | nr | 80 | 20-69 | Chinese | Su et al, 1994 |
| | 446.9(84.3) | 427.3(85.3) | 55 | 60-69 | U.S. Adults | Desrosiers et al, 1995 |
| | 415.5(89.2) | 396.9(83.3) | 48 | 70-79 | | |
| | 338.1(70.6) | 314.6(68.6) | 40 | 80+ | | |
| | 481.2(73.5) | 457.7(70.6) | 40 | 18-84 | U.S. Adults | Richards, 1997 |
| | 451.8(nr) | 410.6(nr) | 34 | 19-45<br>29(nr) | Office workers | Josty et al, 1997 |
| | 514.5(nr) | 496.9(nr) | 38 | 16-56<br>30(nr) | Light manual (garage workers) | |
| | 526.3(nr) | 525.3(nr) | 32 | 17-65<br>43(nr) | Heavy manual (farmers) | |
| ***Female*** | 281.3(nr) | 218.5(nr) | (nr) | 18-65 | U.S. Adults | Nemethi, 1952 |
| | 310.7(nr) | 284.2(nr) | 80 | 18-52 | Steel mill applicants | Schmidt & Toews, 1970 |

| | | | | | |
|---|---|---|---|---|---|
| 241.1(nr) | 219.5(nr) | 50 | 17-60 | U.S. Adults | Swanson et al, 1970 |
| 240.1(43.1) | 214.6(42.1) | 61 | 18-67 | U.S. Adults | Young et al, 1986 |
| 210.7(54.9) | nr | 26 | 16-28<br>19.1(1.6) | College students | Balogun et al, 1991 |
| 360.6(71.5) | 334.2(71.5) | 109 | 16-63<br>32(nr) | U.S. Adults | Crosby et al, 1993 |
| 273.4(55.9) | nr | 80 | 20-69 | Chinese | Su et al, 1994 |
| 247.9(47.0)<br>232.3(50.0)<br>196.0(42.1) | 231.3(46.1)<br>215.6(46.1)<br>181.3(43.1) | 56<br>59<br>29 | 60-69<br>70-79<br>80+ | U.S. Adults | Desrosiers et al, 1995 |
| 289.1(60.8) | 272.4(5.7) | 34 | 18-84 | U.S. Adults | Richards, 1997 |

## Figures


**FIGURE 3:** Scale for rating peak hand force (from Latko et al. 1997b).

| | **Score** **{**tc "**Score** " \l 5**}** | **Verbal Anchore** **{**tc "**Verbal Anchore** " \l 4**}** |
|---|---|---|
| | 0 | Nothing at all **{**tc "Nothing at all " \l 4**}** |
| | 0.5 | Extremely weak (just noticeable) |
| | 1 | Very weak |
| **{**tc " " \l 5**}** | 2 **{**tc "2 " \l 5**}** | Weak (light) **{**tc "Weak (light) " \l 5**}** |
| | 3 | Moderately |
| | 4 | |
| | 5 | Strong (heavy) |
| | 6 | |
| | 7 | Very strong |
| | 8 | |
| | 9 | |
| | 10 | Extremely strong (almost max) |
| | | Maximal |

**FIGURE 4:** Borg Category-Ratio Scale for estimating hand forces

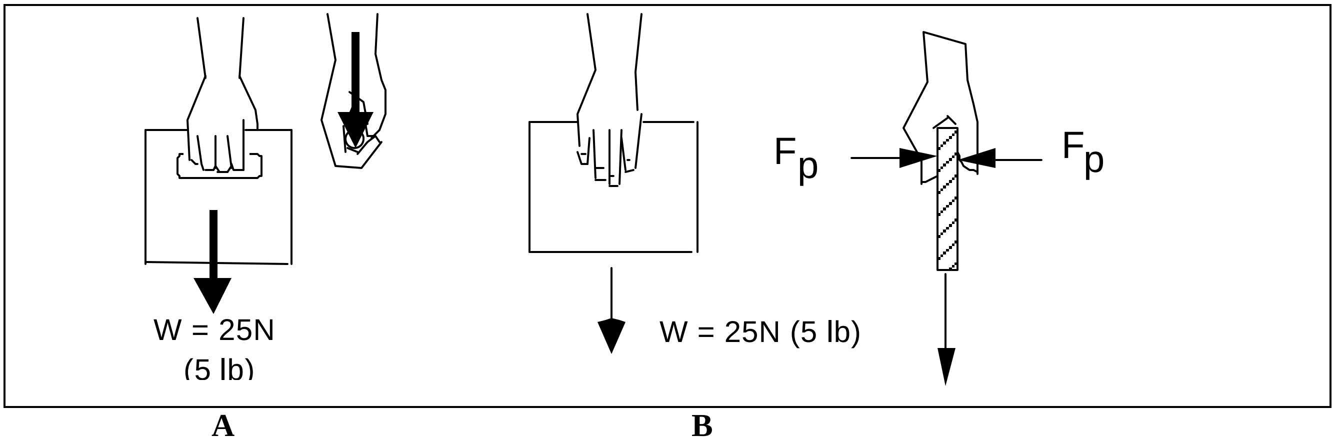
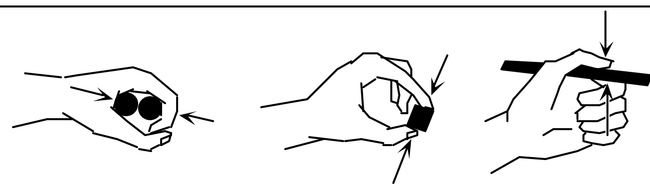



**FIGURE 5:** In **A**, the worker must flex his fingers to oppose the weight of gravity on the object. In **B**, the object must be pinched hard enough, $\mathbf{F}_p$, to produce sufficient friction, $\mathbf{F}_f$, to overcome the weight, **W**.



| | Male | | Female | |
|---|---|---|---|---|
| | Major | Minor | Major | Minor |
| Grip Strength | 466.5 | 441.0 | 241.1 | 219.5 |
| Chuck Pinch | 77.4 | 73.5 | 51.0 | 48.0 |
| Pulp Pinch: | | | | |
| Digits I-II | 51.9 | 47.0 | 35.3 | 32.3 |
| Digits I-III | 54.9 | 55.9 | 37.2 | 33.3 |
| Digits I-IV | 37.2 | 35.3 | 24.5 | 23.5 |
| Digits I-V | 22.5 | 21.6 | 16.7 | 15.7 |
| Lateral Pinch | 73.5 | 69.6 | 48.0 | 46.1 |

**FIGURE 6**: Average male and female hand strengths in newtons for selected postures (from Swanson et al., 1970).